United States
Department of
Agriculture

Agricultural
Research
Service

ARS-41

September 1985

Experimental Delayed-Light-Emission Meter for Horticultural Crops

ABSTRACT

Forbus, W.R., Jr., G. Allan Hardigree, and James H. Adams 1985. Experimental Delayed-Light-Emission Meter for Horticultural Crops. U.S. Department of Agriculture, Agricultural Research Service, ARS-41, pp. 12

Equipment for measuring the delayed light emission (DLE) from horticultural crops was developed for use in a long-range study to determine the feasibility of sorting different fruits and vegetables according to maturity by measuring the light emitted from them several seconds after illumination by a controlled light source. Preliminary tests with tomatoes showed that the magnitude of detector response to DLE decreased during apparent ripening as indicated by an increase in red color.

KEYWORDS: chlorophyll, delayed light emission, DLE, tomato sorting, tomatoes, tomato maturity, tomato quality

---

Copies of this publication may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

The Agricultural Research Service has no additional copies for free distribution.

CONTENTS

245

EXPERIMENTAL DELAYED-LIGHT-EMISSION METER FOR HORTICULTURAL CROPS

by W.R. Forbus, Jr., G. Allan Hardigree, and James H. Adams[1]

INTRODUCTION

Plants materials that have been illuminated emit very-low-intensity light for several seconds, or minutes, after the illumination is removed (7). This delayed light emission (DLE) was initially believed to be caused by a slight reversibility of the photosynthetic process in which excited chlorophyll was regenerated chemically (7, 1). However, later work showed that other compounds in green plants also contributed to DLE (8, 5).

All living plants contain chlorophyll and probably produce DLE; therefore it has been suggested that certain fruits and vegetables might be classified according to maturity by measuring the light emitted from them several seconds after illumination by a controlled light source (5). These researchers found that DLE was related to surface chlorophyll concentration in lemons, which is known to be related to maturity. DLE related to apparent chlorophyll concentration was also observed for apples, apricots, bananas, bell peppers, nectarines, olives, onions, oranges, peaches, persimmons, plums, pomegranates, and tomatoes.

More recently, other researchers have investigated the feasibility of applying DLE to determine the maturity of tomatoes (2), satsuma oranges (3), fresh tea leaves (6), and bananas (4).

Previous work has demonstrated that DLE has an unusually high potential for application in the measurement of fruit and vegetable maturity; however, automated sorting equipment using this principle has not been developed. This technique has not been exploited, because so many variables affect the duration and intensity of DLE that, unless they are strictly controlled and optimized, reproducibility of measurements is not always satisfactory. Variation of parameters of preillumination (light composition, intensity, and duration) and conditions of plant pretreatment (temperature, composition of the medium, pH, and illumination) are known to affect the duration and intensity of DLE.

The objective of the work reported here was to develop experimental equipment for use in a long-range study to measure the DLE of selected horticultural crops at different stages of maturity and to further investigate variables affecting DLE in order to optimize design specifications for automated sorting equipment.

APPARATUS AND PROCEDURES

Design Considerations

Equipment for measuring the DLE from horticultural crops must incorporate the following components: (1) a light source for illuminating the sample to activate the DLE, (2) a totally dark enclosure in which the sample can be isolated for measuring the DLE after the illumination is removed, (3) a photomultiplier tube (PMT) mounted inside the totally dark enclosure for detecting the light emitted from the sample, (4) an amplifier for amplifying the low-intensity signal, and (5) a recorder for recording the intensity of the light emitted as a function of time.

The essential components of an experimental DLE meter can be combined in a number of different configurations. For example, the light source and the PMT can either be located in the same or separate enclosures. Also, illumination may be from readily available light sources such as incandescent and fluorescent lamps, or filters may be used to provide monochromatic light. The specific design configuration used is not critical provided it

[1] Forbus is an industrial engineer, Hardigree was formerly an engineering technician, and Adams is an engineering technician at the Richard B. Russell Agricultural Research Center, Agricultural Research Service, U.S. Department of Agriculture, Athens, GA 30613.

permits careful control over all variables that are known to affect DLE.

The primary considerations governing the overall design of the DLE meter developed in this study were simplicity, flexibility, accuracy, and applicability of results obtained to the development of automated sorting systems for horticultural crops.

Equipment Design and Operation

The overall design configuration of the experimental DLE meter is shown in the schematic drawing of figure 1. The dual compartment case of the meter was fabricated with No. 18-gauge sheet aluminum. The DLE from the sample is measured in the lower compartment, and the electrical and electronic components are housed in the upper compartment. The main power switch (SW1) is at the top and rear of the left side of the case, and operating controls are mounted on a panel in the front of the upper compartment as shown in the front view.

The sample (S) from which the DLE is to be measured is nested in a foam rubber sample holder (A) attached to the bottom of the sample drawer, which can be manually rolled in and out of the lower compartment on the drawer track. The sample is illuminated by a 100-watt tungsten lamp (L) with the drawer open as shown in the "side view during illumination" portion of figure 1. The lamp operates independently from all other meter components, providing the flexibility of being able to vary the composition, intensity, and duration of sample illumination. The end window of the photomultiplier tube (PMT) protrudes into the lower compartment and, during illumination of the sample, is protected from infiltrating light by a closed camera shutter (SH). The plunger of a solenoid (SOL) is attached to the lever that opens and closes the shutter. Solenoid action and recorder operation are controlled by the door switch (SW2), which is opened and closed by the opening and closing of the sample drawer. With the drawer open as shown in the "side view during illumination" portion of figure 1, the door switch is open, the shutter is closed, and the recorder is off.

To measure the DLE from the sample, the main power switch (SW1) is turned on and the voltage control (P1) on the front panel is adjusted to obtain a reading of 1,800 V on the digital display (DISP). The voltage control can be adjusted to supply any voltage between 0 and 2,000 V to the cathode of the photomultiplier tube. The selector switch (SW3) is positioned on AUTO, which provides a 0.25-s delay between the closing of the door switch (SW2) and the opening of the shutter (SH). It also permits varying the time the shutter remains open from 0 to 90 s by adjusting the timer control (P2). The time delay between closing the sample drawer and opening the shutter prevents the photomultiplier tube from detecting any signal from the sample until the drawer is completely closed to eliminate interference from infiltrating light. Gasket material around the door and in all seams of the case makes the lower compartment totally dark during measurement.

When the sample drawer is closed as shown in the "side view during measurement" portion of figure 1, the top edge of the drawer closes the door switch (SW2). After the 0.25-s delay, the solenoid (SOL) is energized and the recorder is turned on. Movement of the solenoid plunger opens the shutter (SH), and light emitted from the sample (S) is detected by the photomultiplier tube. The signal is amplified and then recorded with a Heath Model SR-204 strip-chart recorder for the duration of time selected with the timer control (P2). At the end of the preset time, the solenoid is deenergized, causing the shutter to close and the recorder to be turned off. To prevent the inadvertent opening of the sample drawer before the test interval is complete, a light-emitting diode (LED) is provided on the front panel and is lighted when the shutter is open and testing is in progress. The shutter may be kept open for periods longer than 90 s by moving the selector switch (SW3) to MANUAL and returning the timer control (P2) to zero immediately after the shutter opens. This causes the shutter to remain open and the recorder to operate until the door switch (SW2) is opened by manually opening the sample drawer.

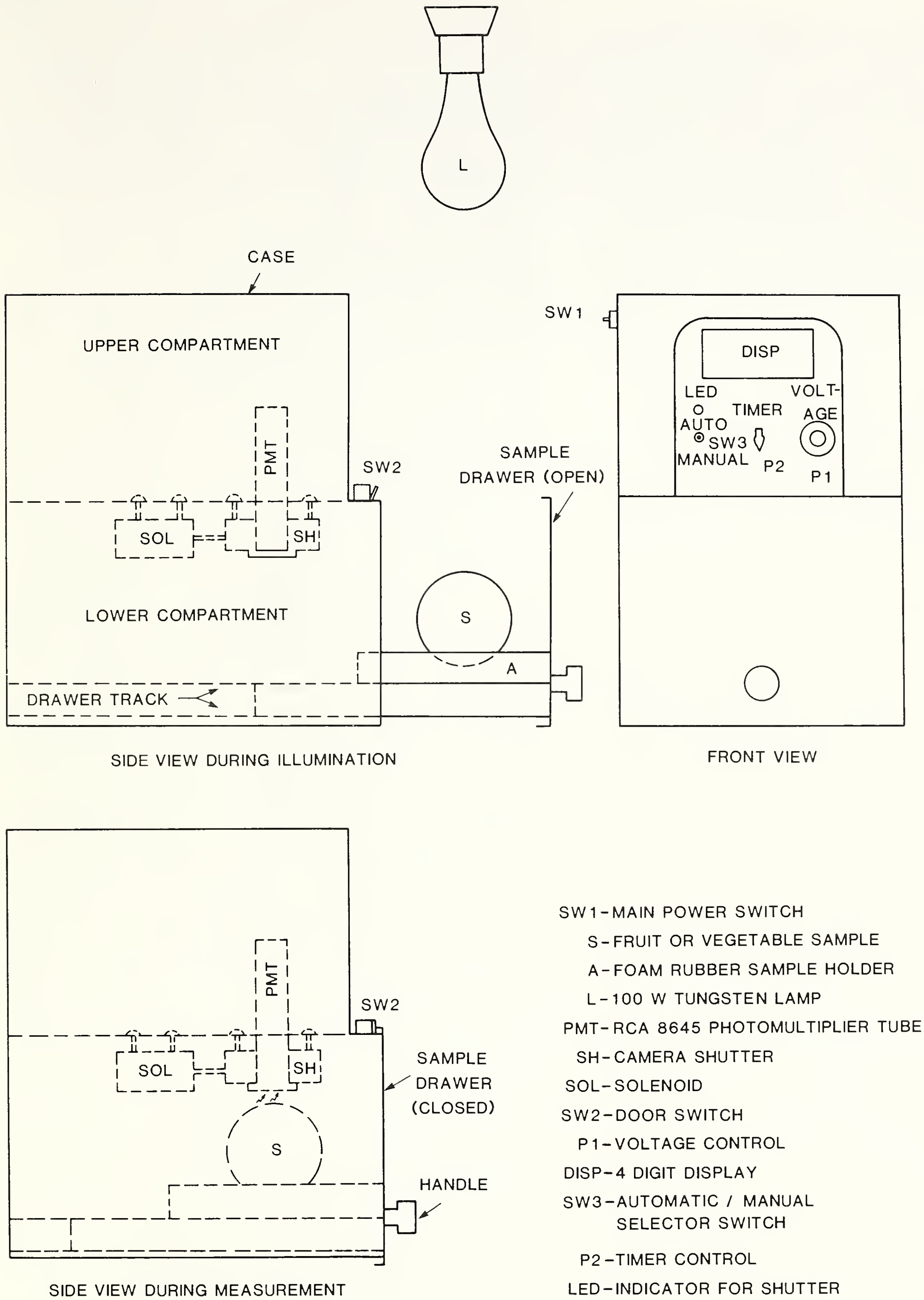

Figure 1. Schematic drawing of experimental DLE meter.

This design incorporates considerable flexibility in that the size of the lower compartment is adequate for measuring the DLE from a variety of different horticultural crops. It will accommodate spherical samples with diameters from less than 2.54 cm to about 10.16 cm. Also, during measurement, the distance between the end window of the photomultiplier tube and the sample surface can be varied by changing the thickness of the foam rubber sample holder (A).

CIRCUIT DESIGNS

A block diagram for the DLE meter is shown in figure 2. The meter incorporates the following major circuits: (1) the power circuit, (2) the shutter-timer circuit, and (3) the photomultiplier-tube amplifier circuit.

Power Circuit

The distribution of power to the various components of the meter is shown in figure 2. Line voltage (120 V AC) is applied to the low-voltage power supply (PS1) when the main power switch (SW1) is closed. A 1-A fuse protects all circuits from overload. The low-voltage power supply (PS1) supplies +15 V and -15 V to both the high-voltage power supply (PS2) and the photomultiplier-tube amplifier circuit and +5 V to operate the digital display (DISP). It also supplies +15 V to the shutter-timer circuit when the door switch (SW2) is closed. The high-voltage power supply (PS2) permits applying any voltage between 0 and 2,000 to the cathode of the photomultiplier tube by adjusting the voltage control (P1). The high-voltage supply also applies a voltage between 0 and 2 to the digital display (DISP) that is proportional to the voltage between 0 and 2,000 being applied to the photomultiplier tube. The voltage at the cathode of the photomultiplier tube is displayed in four digits. Power is supplied continuously to all components except those of the shutter-timer circuit as long as the main switch (SW1) is closed. However, no signal can be detected by the photomultiplier tube until the shutter is opened.

Shutter-Timer Circuit

A circuit diagram for the shutter-timer circuit of the DLE meter is shown in figure 3. This circuit controls the opening and closing of the shutter, the time the shutter remains open, and the turning on and off of the recorder.

When the door switch (SW2) is open, Vcc (+15V) from the low-voltage power supply (PS1) charges capacitors C1 and C3. When the door switch (SW2) is closed with the selector switch (SW3) positioned on automatic (AUTO), capacitor C1 discharges and current flows to pin 6 of the dual timer (T1), triggering the first timing stage. The RC network R2-C2 provides the 0.25-s delay after which current flows from pin 5 causing capacitor C3 to discharge and current to flow to pin 8, triggering the second timing stage. During this second stage, current is allowed to flow from pin 9 of the timer through the diode (D1) and the relay (K1). When the relay (K1) is energized, the recorder switch (SW4) closes to the normally open (NO) position, allowing current to flow through both the shutter solenoid (SOL) and the LED, which opens the shutter and exposes the end window of the photomultiplier tube as well as actuating the recorder. Current continues to flow from pin 9 for a period between 0 and 90 s, depending on the setting of the timer control (P2). At the end of the preset time, capacitor C5 discharges through pin 13 and current ceases to flow from pin 9. This deenergizes the relay (K1), which causes the recorder switch (SW4) to return to the normally closed (NC) position that deactivates the recorder and cuts off current to both the shutter solenoid (SOL) and the LED. If the selector switch (SW3) is moved to MANUAL with the door switch (SW2) closed, the timing circuit is bypassed and current flows continuously to the relay (K1), which keeps the shutter open and the recorder on until the door switch (SW2) is opened by manually opening the sample drawer.

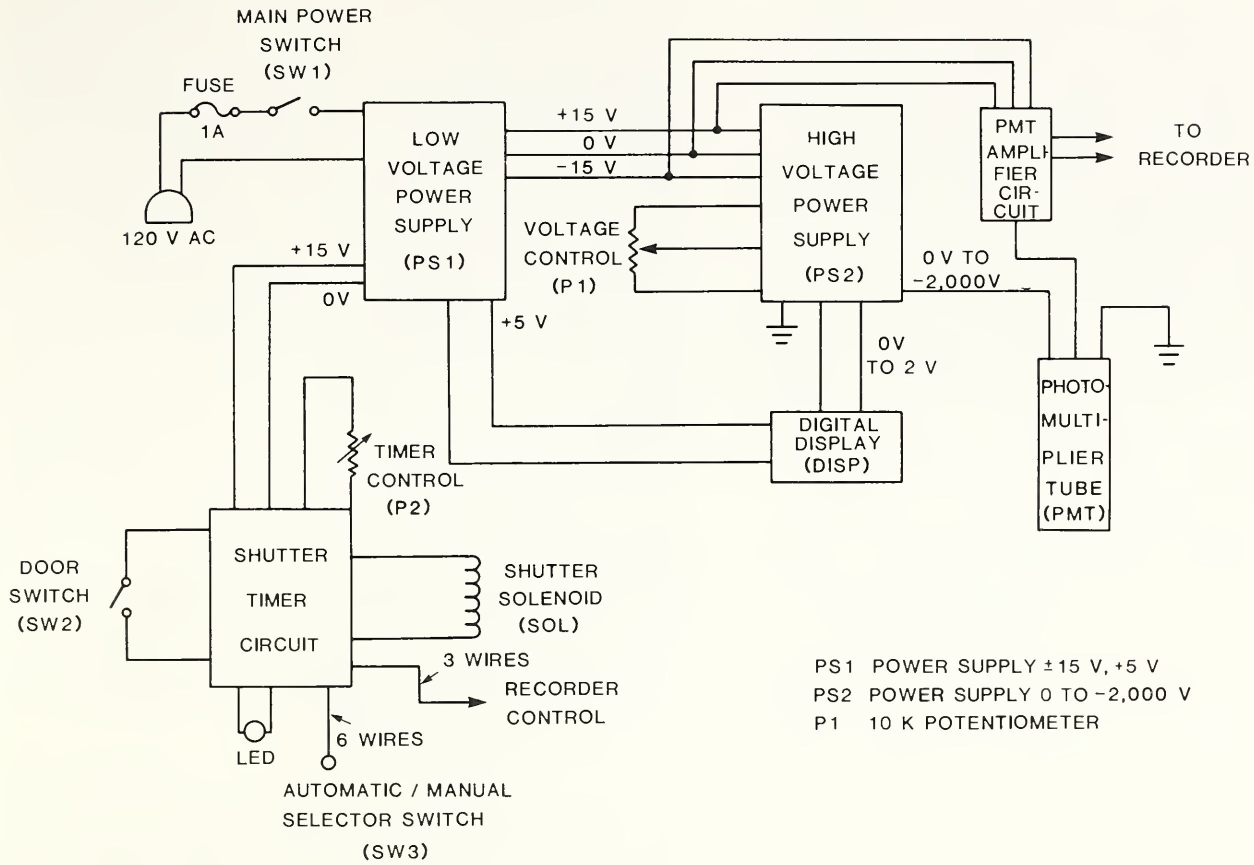

Figure 2. Block diagram showing major circuits for the DLE meter.

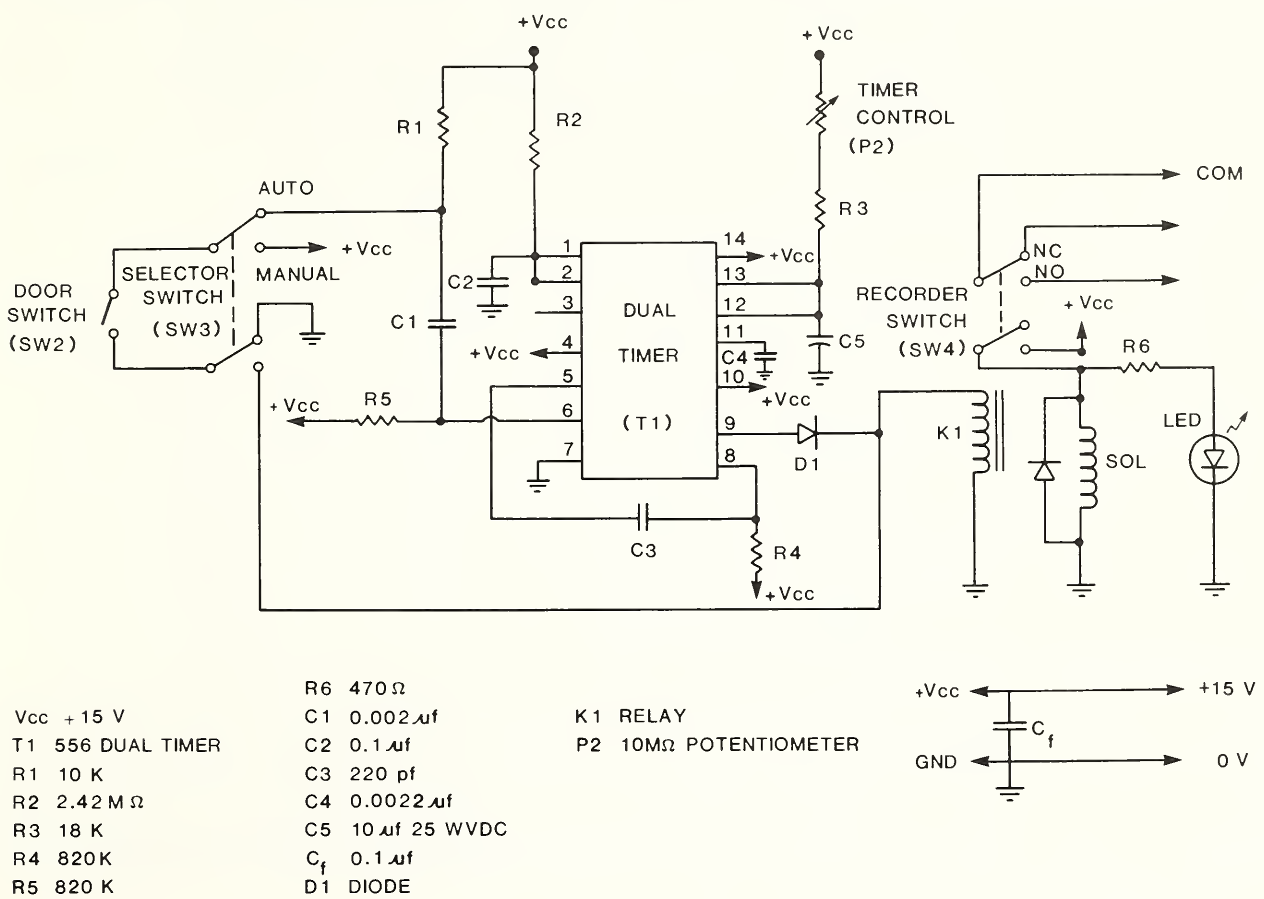

Figure 3. Wiring diagram of shutter-timer circuit.

Photomultiplier-Tube Amplifier Circuit

The photomultiplier-tube amplifier circuit for the DLE meter is shown in figure 4. Power is supplied to the operational amplifier (OA) by applying +15 V to terminal 7 and -15 V to terminal 4. Light emitted from the sample causes a low-intensity current to flow from the anode of the photomultiplier tube. The function of the amplifier circuit is to amplify this very-low-intensity current and convert it to a recordable DC voltage. The input current flows to terminal 2 of the operational amplifier (OA), causing current to flow through the load resistor (R9), the feedback resistor (R8), and the signal resistor (R10). The output DC voltage to the recorder is linearly proportional to the input current. The amplifier is essentially a current-to-voltage converter, and components were designed so that a 1-μA input current results in a 1-V output to the recorder.

EQUIPMENT TESTS

The experimental DLE meter was tested to determine the effect of apparent fruit or vegetable maturity on the magnitude of detector response to DLE. Tomatoes were selected for preliminary tests because during ripening they undergo a large change in chlorophyll concentration that has been shown to be highly correlated with the ability to produce DLE. During ripening, tomato color gradually changes from green to red because of the decomposition of chlorophyll and the formation of the carotenoid pigments carotene and lycopene. DLE sorting for maturity should be especially applicable to tomatoes for the fresh market because present marketing practice dictates that they be harvested at a stage of greenness that will allow them to ripen to their optimum maturity in transit to the consumer.

In November 1983, a sample of 25 tomatoes of the Duke variety were obtained from a commercial packinghouse in South Carolina. According to the United States Standards for Grades of Fresh Tomatoes (9), all

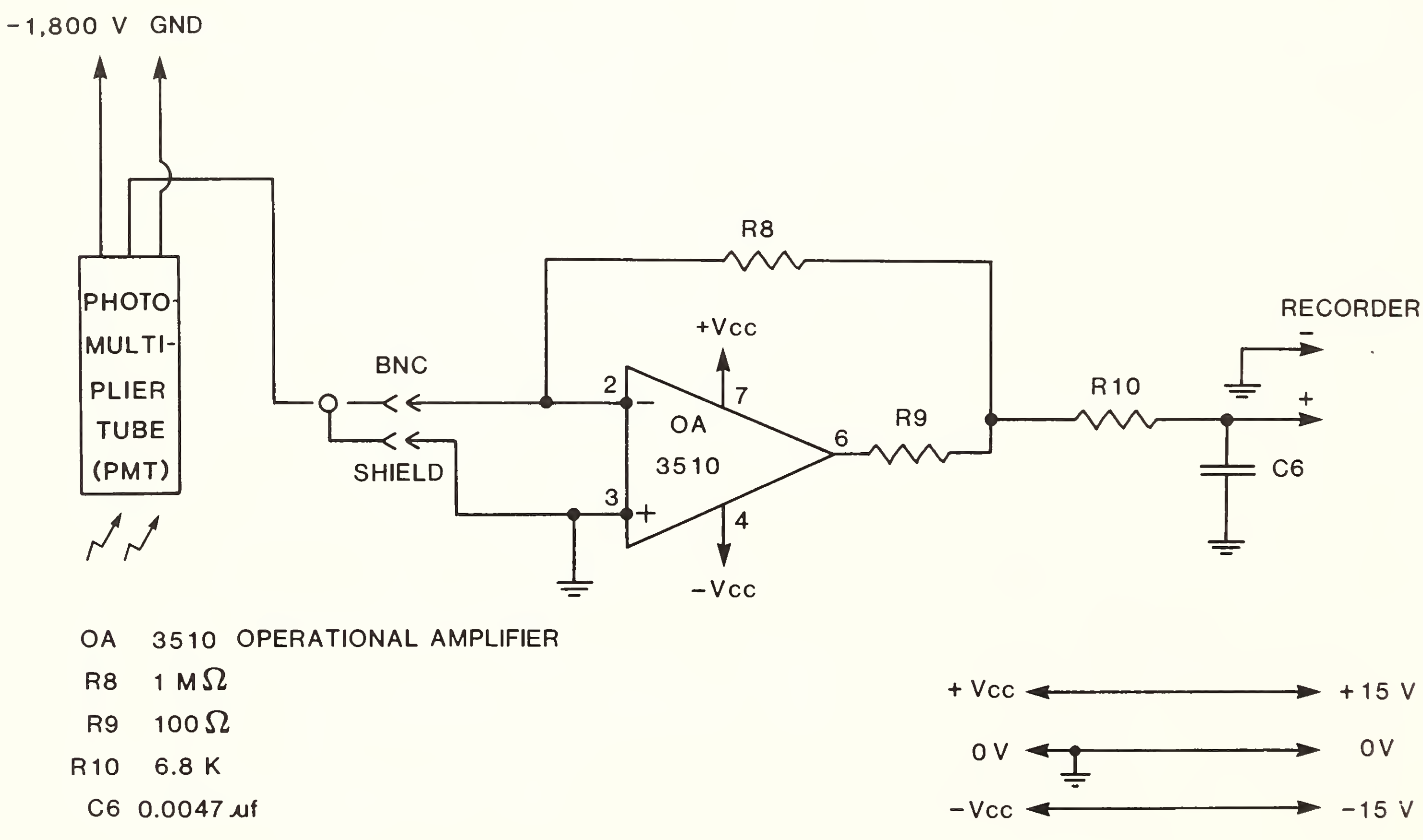

Figure 4. Photomultiplier-tube amplifier circuit.

tomatoes conformed to the "green" color classification (surface of tomato completely green in color) and the "large" size designation (64 mm minimum diameter; 73 mm maximum diameter). About 12 h after harvesting, four tomatoes from the sample were selected for a ripening study based on a visual determination of their similarity in greenness of color, overall shape, and absence of damage. The four tomatoes were coded for identification and then stored in the dark in a constant-temperature-and-relative-humidity chamber maintained at 20°C and 88 percent RH. DLE measurements were taken on these four tomatoes at selected intervals through 24 days of storage. Observations were made daily to determine the day of storage on which "color-break" (the appearance of a trace of pink or red color on the blossom end) occurred for each tomato.

For each DLE measurement, each tomato was held for 10 min in darkness to eliminate the effect of previous excitation. Each tomato was illuminated for 5 s with the 100-watt tungsten lamp, and the DLE measurement was made 0.25 s after the illumination was removed for about 30 s. Tomatoes were illuminated and DLE measurements taken with the blossom end exposed to the end window of the photomultiplier tube. After each storage time, three DLE measurements were made on each tomato.

RESULTS AND DISCUSSION

The means of the three DLE measurements taken on each of the four tomatoes at each storage time are given in table 1. The small magnitude of the delayed light prevented accurate calibration of the detector; therefore DLE intensities are reported as volts of detector response.

Table 1. Detector response to DLE for four tomatoes ripened for 24 days at 20°C and 88 percent RH

Days of storage	Means[1] of detector response to DLE (volts) and day of storage color-break occurs[2] for tomato--			
	1	2	3	4
1	0.490	0.470	0.530	0.520
4	.470	.390	.470	.470
7	.420	.220 (CB)	.440	.470
9	.390	.090	.420	.410
13	.370	.010	.420	.430
15	.320	.006	.400	.420
16	.190 (CB)	.005	.260	.260
17	.140	.003	.250	.260
18	.120	.003	.200 (CB)	.260
21	.050	.003	.130	.180 (CB)
22	.030	.003	.100	.180
24	.012	.002	.040	.080

[1]Means of three measurements on each tomato at each storage time.
[2](CB) in each column designates DLE value for tomato on day of storage that color-break occurred.

The data show that the magnitude of detector response to DLE after 1 day of storage varied among the four tomatoes that were visually judged to be at the same stage of greenness. The DLE from each tomato gradually decreased during storage until color-break occurred and then decreased more rapidly as ripening continued. The wide range in days of storage to color-break for the four tomatoes at the same apparent stage of maturity demonstrates the difficulty of visually sorting tomatoes at a stage of greenness that will allow them to ripen at the same time. The fact that the tomatoes having the lower initial DLE values achieved color-break before those having higher values indicates that DLE sorting for maturity is feasible. The technique should also be applicable for other fruits and vegetables for which marketing conditions dictate sorting during a stage of greenness.

The typical recorder response to DLE is illustrated by the recorder response curves obtained for tomato 2 at storage times through 13 days (fig. 5). Point A on the baseline of the response curve for 1 day of storage was the instant the shutter opened exposing the tomato to the photomultiplier tube. Point B is the magnitude of detector response to DLE about 0.25 s after the illumination is removed, and point C is the instant the recorder is turned off. These response curves show that the maximum DLE intensity occurs immediately after the illumination is removed and then rapidly decays. The decrease in maximum recorder response at each storage time also illustrates the decrease in DLE intensity during the ripening process.

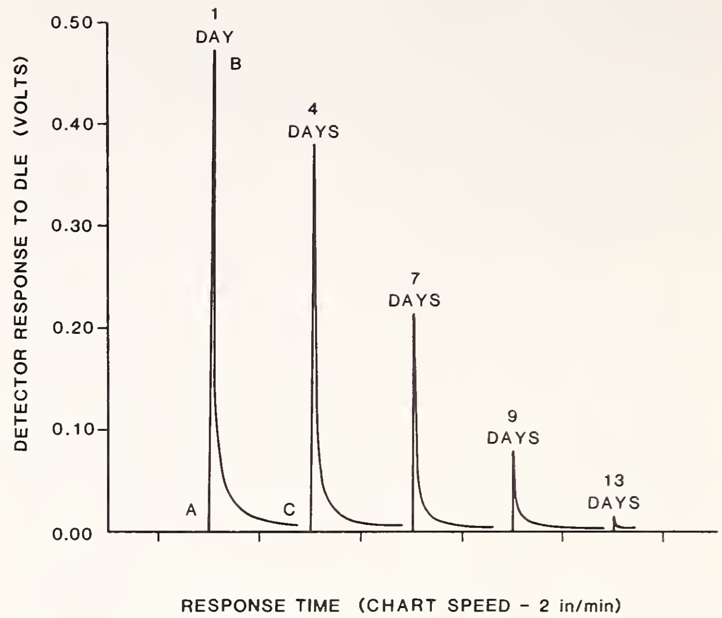

Figure 5. Recorder response curves for tomato 2 at storage times through 13 days. (A) is instant recorder is turned on, (B) is maximum detector response to DLE, and (C) is instant recorder is turned off.

LITERATURE CITED

1. Arnold, W. and Davidson, J.B. 1954 The identity of the fluorescent and delayed light emission spectra in chlorella. J. Gen. Physiol. 37:677-684.

2. Chuma, Y. and Nakaji, K. 1976 Optical properties of fruits and vegetables to serve the automatic selection within the packinghouse line (4)--Delayed light emission as means of automatic selection of tomatoes. J. Soc. Agric. Mach. Japan 38(2):217-244.

3. Chuma, Y., Sein, K., Kawano, S., and Nakaji, K. 1977 Delayed light emission as a means of automatic selection of satsuma oranges. ASAE Trans. 20(5):996-1000.

4. Chuma, Y., Nakaji, K., and Ohura, M. 1980 Maturity evaluation of bananas by delayed light emission. ASAE Trans. 23(4):1043-1047.

5. Jacob, F.C., Romani, R.J., and Sprock, C.M. 1965 Fruit sorting by delayed light emission. ASAE Trans. 8(1):18-19, 24.

6. Nakaji, K., Sagiura, Y., and Chuma, Y. 1978 Delayed light emission of green tea as a means of quality evaluation (1)--Delayed light emission of fresh tea leaves. J. Soc. Agric. Mach. Japan 39(4):483-490.

7. Strehler, B.L. and Arnold, W.A. 1951 Light production by green plants. J. Gen. Physiol. 34:809-820.

8. Tollin, G., Fumimori, E., and Calvin, M. 1958 Action and emission spectra for the luminescence of green plant materials. Nature 181:1266-1267.

9. U.S. Department of Agriculture. 1973 United States standards for grades of fresh tomatoes. 38 Fed. Regis. 23931.